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APPENDIX A

PROGRAMMING CONSIDERATIONS AND PRINTED OUTPUT FROM THE MODEL

A GREAT DEAL OF DEVELOPMENT and testing remains before the NBER model can be used to evaluate programs and policies. Even so, the current version of the NBER model advances the state of the art of building urban simulation models.

In Chapter 9 we described some of our own plans for further development of the model. We hope, however, that others will develop the model along other lines or incorporate some of the model's novel features into urban simulation models of their own design. In this appendix we seek to facilitate this process by providing a brief discussion of the programming of the NBER model.¹

This appendix contains a discussion of the running times of the NBER model and its submodels, followed by a display of illustrative printed output from the program. These sample tables and the supporting narrative provide some of the sense of model operations missing from chapters 3 and 4. However, the final section, a brief description of programming considerations, will probably interest only programmers and computer enthusiasts.

1. We considered including flow charts and program listings but did not provide these materials, which run to 130 pages, because the audience is small and because the NBER Urban Simulation Model is under continuous development. Therefore, persons interested in using the NBER model or in developing it further should contact the authors to obtain program listings of more highly developed and improved versions of the model. We will make every effort to make both up-to-date listings and program decks available to interested parties.

Computer Running Times for the Model

The model has been run on both the IBM 360/67 and the IBM 360/91. A year's simulation requires less than two minutes of CPU (central processing unit) time on the 360/91 and approximately seven minutes of CPU time on the 360/67. Table A.1 shows representative running times by submodel for the two machines. These times depend upon not only the size of the problem but also the compiler and the input data. Considerable variation has been noted between calibration runs and between years within the same calibration run. In Chapter 9 we described a number of changes in program design incorporated into Pittsburgh I that reduced the program's running time while at the same time increasing its dimensions. Running times of Pittsburgh I are about half those of the Detroit Prototype.

Level G compilation of FORTRAN routines results in object programs which generally run much more slowly than Level H (option 2) compilations of the same routine operating on the same data.

Table A.1
Table of Running Times

| Submodel | Program Subroutines | Typical Running Times ^a | |
|-----------------|--------------------------------------|------------------------------------|-----------------------------|
| | | IBM 360/91 (CPU seconds) | IBM 360/67 (CPU seconds) |
| Filtering | <i>FILTER, FLTR</i> | 0.35 | 0.87 |
| Industry | <i>NDSTRY</i> | 0.10 | 0.20 |
| Mover | <i>MOVE, SCOOP</i> | 3.40 | 31.56 |
| Demand | <i>DEMND</i> | 1.31 | 7.73 |
| Supply | <i>SUPPLY, SORTS, SORTH1, SELECT</i> | 5.14 | 26.57 |
| Assignment | <i>MARKET, ENCODE, MATCH, UPDATE</i> | 77.05 | 328.45 |
| Price formation | <i>PFORM</i> | 1.15 | 3.44 |
| Other | <i>MAIN, TRVLU</i> | 9.78 | 21.77 |
| Total | | 98.28 | 420.59 |

Note: Subroutine *INPUT* reads cards for the initial start up, and is not therefore included above. It required 5.15 CPU seconds on the IBM 360/91 and 10.91 CPU seconds on the IBM 360/67.

a. For each year simulated. Problem size: 19 work zones, 44 residential zones, 27 housing types, 72 household types.

Running times for the movers submodel have been reduced 50 per cent by using H-compiled object decks on the IBM 360/91 and 20 per cent by using H-compiled decks on the 360/67 under the same conditions. The H compilation appears to make more difference on a 360/91 because the machine's sequence of operation is frequently quite different from the sequence of steps encountered in the program.

The advances in computer technology cannot be overstated. Five years ago this model would have been so expensive to run that very little, if any, use could have been made of it in testing alternative policies. Today the operating costs of the model are almost trivial by comparison. We have had experience in programming models beginning with the IBM 709 in 1959 and subsequently with the IBM 7090, the 7094, the 360/50, the 360/67, and now the 360/91. Past experience suggests that a single year's simulation run of the Detroit Prototype would have taken from forty-five minutes to an hour of computation time on a 7094 and probably another twenty minutes for tape storage. This assumes, of course, that enough core storage existed on a 7094 to run a model of this size, and that is not true by a factor of two. An IBM 7090 would have required at least four hours, and the old 709 would have taken a whole day for a single year's run. In the late 1950s the Detroit Prototype would have cost at least \$7,200 per simulated year, and today it costs less than \$50 for the same simulation on the 360/91 and \$90 per simulated year on the IBM 360/67. Although these figures are very reasonable, one must remember that the model will typically be run for several simulation periods, so the cost per simulation run is a multiple of the single-period cost.

Printed Output from the Program

In the course of a run, the Detroit Prototype of the NBER Urban Simulation Model performs a great many operations in order to simulate the processes of urban growth and development. The quality level of the housing stock is altered, employment levels are changed, moving households are generated, the stock of dwelling units is augmented, and movers are allocated to the available units. In

addition to these primary tasks, many bookkeeping functions are performed as arrays are updated, prices are formed, and trip distributions are revised. Indeed, the model performs so many functions in each time period that a complete reporting of even one time period's activities would produce an indigestible quantity of computer printout. Therefore, it is necessary to have an efficient way of summarizing and controlling the information produced by the model during each run.

Since the model will be used for many purposes, as sensitivity analyses are run and different policy impact studies are carried out, a series of print control options has been incorporated which enable the model output to be varied between different simulation runs as well as between different time periods within a run. The output provided by the model during each time period is controlled by a series of print "switches" that are reset for each model period. At the beginning of a time period the model reads three cards which specify which summary tables are to be produced for that period. This option permits the analyst to obtain a full report of the model's activities in some periods and an abbreviated or summary report of activities for others. The list of reports controlled by the print switch option in the Detroit Prototype is shown in Table A.2.

Although most reports can be controlled by the output option, some are automatically produced during every time period. For example, in each time period the model maps location rents or land prices for each residence zone. Figure A.1, a plot of land prices by residence zone for a calibration run, illustrates these maps. The values are printed in positions which approximate the location of each of the 44 residence zones in the Detroit modeled area. All maps indicate the housing type and the year of the simulation run.

The exhibits included in this appendix illustrate typical output formats for several of the print switch options. Exhibits A.1 and A.2 illustrate two of the five possible tables which summarize the activities performed by the filtering submodel. They show the number of units of each structure group that have filtered between quality levels 1 and 2 in each of the forty-four residence zones. The first six structural groups are single-family detached units. The last three are multiple-family structures.

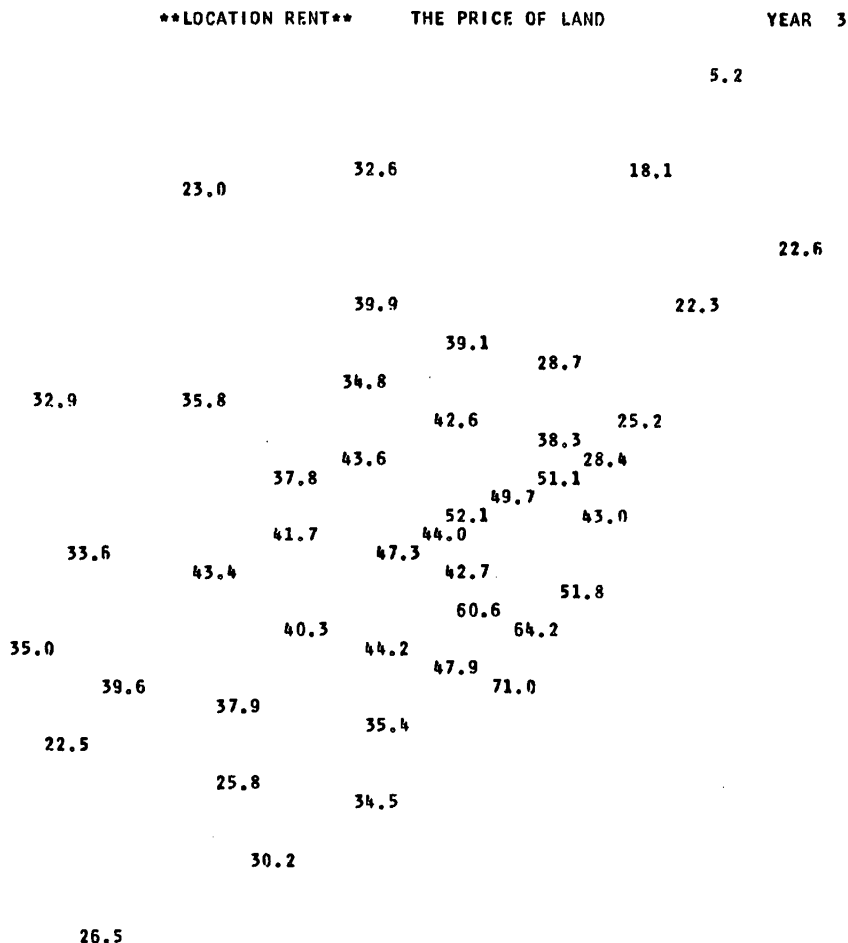
The supply submodel also has several summary report options.

Table A.2
Print Control Options

| Option Number | Causes the Printing of: |
|---------------|---|
| 1 | Report on filtering activities performed |
| 2 | List of profit scores too low to be used |
| 3 | Table of structural conversions performed; by zone and type of conversion made (prohibitions by zoning ordinances are included in this list) |
| 4 | Option 3 including impossible but potentially profitable conversions (impossible because required inputs do not exist in the zone). |
| 5 | Summary of conversions which were performed in each zone (input and output housing type omitted) |
| 6 | List of unfilled demands, numbers created as outputs, and numbers consumed as inputs for each house type (zone of activities is omitted) |
| 7 | Report of employment updates which attempt to cause negative totals within a work zone (nonnegativity is maintained whether reported or not) |
| 8 | Report of new employment totals by work zone and employment group |
| 9 | Report of net change in employment by work zone and employment group |
| 10 | Report of prices of all housing types and land types by residence zone which were in effect at the beginning of the simulation year |
| 11 | Report of initial estimates of prices for all housing and land types in each residence zone resulting from the market |
| 12 | Report of shadow prices (location rent) on all housing types in each residence zone |
| 13 | Report of adjusted prices on all housing and land types, which reflect a blend of initial estimates and old prices; will be used as next year's prices |
| 14 | Report of net change in prices between this year's prices and next year's prices |
| 15 | Report of household totals by residence zone and income class after movers have been located |
| 16 | Report of net change in household totals by residence zone and income class |
| 17 | (Unused at this time) |
| 18 | (Unused at this time) |
| 19 | List of inputs to each market problem for each housing type: number of families by workplace and income, and number of dwelling units available by residence zone |
| 20 | List of average perceived travel cost for each solution of the market problem; one per housing type |
| 21-70 | List of solutions to the market problem for house-types 1 through 50. |
| 71-120 | Matrix of perceived travel costs used in the market problem for house-types 1 through 50 |

Exhibit A.3 is the first page of the list of conversion activities which were considered by the supply submodel in the sample calibration run. The activities, listed in their order of profitability, consist of all transformations for which inputs were available at the beginning

Figure A.1
Plot of Location Rents (Land Prices) by Residence Zone, Year 3



of the supply submodel's operation. The column labeled "SCORE" indicates the profitability of each activity.

Supply activities in Exhibit A.3 are described by residence zone, ZN; by input housing type, IN; and by output housing type, OUT. Activity levels associated with each possible transformation are described by the number of output structures produced, STRUT OUT; the number of output dwelling units produced, D. U. OUT; and the number of dwelling units used as inputs, D. U. IN. For

Exhibit A.1

Number of Units Filtering Down from Level 1 to Level 2, Classified
by Structural Group

| ZONE | UNITS FILTERING DOWN LEVEL 1 TO LEVEL 2 | | | | | | | | |
|------|---|-------|-------|-------|------|-----|-------|------|-------|
| | STRUCTURE GROUP NUMBER | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 6.0 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 64.0 | 3.0 | 29.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 99.0 | 3.0 | 5.0 |
| 5 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 265.0 | 50.0 | 85.0 |
| 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 817.0 | 84.0 | 833.0 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 168.0 | 30.0 | 2.0 |
| 8 | 0.0 | 39.0 | 0.0 | 0.0 | 0.0 | 0.0 | 984.0 | 16.0 | 284.0 |
| 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 776.0 | 51.0 | 102.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 180.0 | 17.0 | 106.0 |
| 11 | 0.0 | 25.0 | 0.0 | 0.0 | 45.0 | 0.0 | 148.0 | 23.0 | 194.0 |
| 12 | 133.0 | 0.0 | 0.0 | 371.0 | 0.0 | 0.0 | 161.0 | 44.0 | 13.0 |
| 13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 65.0 | 0.0 | 62.0 |
| 14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 43.0 | 0.0 | 4.0 |
| 15 | 303.0 | 377.0 | 0.0 | 0.0 | 0.0 | 0.0 | 14.0 | 3.0 | 10.0 |
| 16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.0 | 0.0 | 2.0 |
| 17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 139.0 | 55.0 | 103.0 |
| 22 | 0.0 | 124.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 23 | 0.0 | 0.0 | 171.0 | 0.0 | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 |
| 24 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 1.0 |
| 25 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 2.0 |
| 26 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 29.0 | 8.0 | 30.0 |
| 27 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 28 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 29 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 44.0 | 11.0 | 34.0 |
| 31 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 43.0 | 11.0 | 22.0 |
| 32 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 | 54.0 | 1.0 | 2.0 |
| 33 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 34 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 35 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 36 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 | 0.0 | 12.0 |
| 37 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 119.0 | 0.0 | 10.0 |
| 38 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 39 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 40 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 41 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 42 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 43 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 44 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

example, the first and most profitable supply activity in Exhibit A.3 occurred in residence zone 22 and involved the conversion of one type-18 dwelling unit (a large, low-quality, single-family unit on a half-acre lot) into two type-23 structures (small multifamily buildings of medium quality with medium-sized apartments). The constraint which determined the level of activity is indicated by the column labeled CONSTRAINT? Three possible constraints could be binding: the input constraint, IN; the demand constraint, DMD; and the zoning constraint, ZN. An asterisk indicates which constraint is effective for each supply activity. For example, the asterisk in the column headed IN indicates that the level of the first supply activity is limited by the number of type-18 units that are available for use

Exhibit A.2

**Number of Units Filtering Up from Level 2 to Level 1,
Classified by Structural Group**

| ZONE | UNITS FILTERING UP LEVEL 2 TO LEVEL 1 | | | | | | | | |
|------|---------------------------------------|-------|-------|-------|-------|-------|-----|------|-----|
| | STRUCTURE GROUP NUMBER | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 42.0 | 37.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 20.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.0 | 0.0 | 743.0 | 187.0 | 122.0 | 26.0 | 0.0 | 0.0 | 0.0 |
| 5 | 35.0 | 0.0 | 0.0 | 0.0 | 247.0 | 68.0 | 0.0 | 0.0 | 0.0 |
| 6 | 85.0 | 79.0 | 368.0 | 29.0 | 369.0 | 67.0 | 0.0 | 0.0 | 0.0 |
| 7 | 213.0 | 0.0 | 575.0 | 88.0 | 82.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | 380.0 | 0.0 | 38.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 0.0 | 0.0 | 123.0 | 0.0 | 0.0 | 80.0 | 0.0 | 0.0 | 0.0 |
| 10 | 379.0 | 66.0 | 0.0 | 224.0 | 97.0 | 91.0 | 0.0 | 0.0 | 0.0 |
| 11 | 51.0 | 0.0 | 18.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 661.0 | 44.0 | 204.0 | 327.0 | 156.0 | 133.0 | 0.0 | 0.0 | 0.0 |
| 14 | 471.0 | 662.0 | 0.0 | 230.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 0.0 | 0.0 | 0.0 | 408.0 | 0.0 | 49.0 | 0.0 | 0.0 | 0.0 |
| 16 | 319.0 | 398.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | 0.0 | 0.0 | 106.0 | 280.0 | 0.0 | 110.0 | 0.0 | 10.0 | 0.0 |
| 18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 130.0 | 0.0 | 0.0 | 0.0 |
| 21 | 857.0 | 133.0 | 0.0 | 299.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 22 | 0.0 | 0.0 | 0.0 | 377.0 | 0.0 | 42.0 | 1.0 | 0.0 | 0.0 |
| 23 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 24 | 0.0 | 360.0 | 156.0 | 49.0 | 0.0 | 28.0 | 0.0 | 0.0 | 0.0 |
| 25 | 0.0 | 111.0 | 0.0 | 0.0 | 214.0 | 59.0 | 0.0 | 0.0 | 0.0 |
| 26 | 0.0 | 253.0 | 141.0 | 593.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 27 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 28 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 29 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 30 | 364.0 | 393.0 | 0.0 | 191.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 31 | 172.0 | 980.0 | 0.0 | 133.0 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 |
| 32 | 154.0 | 0.0 | 0.0 | 0.0 | 0.0 | 26.0 | 0.0 | 0.0 | 0.0 |
| 33 | 0.0 | 186.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 34 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 35 | 0.0 | 0.0 | 0.0 | 82.0 | 0.0 | 31.0 | 0.0 | 0.0 | 0.0 |
| 36 | 28.0 | 36.0 | 0.0 | 0.0 | 35.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 37 | 70.0 | 260.0 | 110.0 | 141.0 | 0.0 | 83.0 | 0.0 | 0.0 | 0.0 |
| 38 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 39 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.0 | 0.0 | 0.0 | 0.0 |
| 40 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 41 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 42 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 43 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 44 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

as inputs in residence-zone 22 during the modeled period. Similarly, from inspection of the constraints column it is apparent that the next two activities are constrained by available input units as well but that the fourth most profitable activity is limited by the demand constraint. The fifth and sixth most profitable activities are again constrained by the number of input units available for transformation while the seventh is limited by both a demand constraint and a zoning prohibition.

All activities in Exhibit A.3 are listed according to their profit score with the exception of the activity which follows the message "SEARCHING *ITEMP* LIST FOR 17 CAUSED BY 5 17 24 4.143."

Exhibit A.3
List of Supply Submodel Activities
Classified by Profitability

'CONVERSIONS' MADE BY CONSTRUCTION INDUSTRY FOR YEAR 17

| ZN | IN | OUT | STRUT OUT | D. U. OUT | D. U. IN | SCORE | CONSTRAINT? |
|---|----|-----|-----------|-----------|----------|-------|-------------|
| | | | | | | | IN DMD ZN |
| 22 | 18 | 23 | 2.0 | 12.0 | 1.0 | 10.6 | * - - |
| 22 | 17 | 22 | 166.0 | 996.0 | 83.0 | 10.0 | * - - |
| 22 | 20 | 23 | 3.0 | 18.0 | 12.0 | 9.7 | * - - |
| 22 | 16 | 22 | 1744.0 | 10464.0 | 872.0 | 8.7 | - * - |
| 22 | 16 | 23 | 1082.0 | 6492.0 | 541.0 | 7.1 | * - - |
| 22 | 11 | 23 | 1460.0 | 8760.0 | 730.0 | 7.1 | * - - |
| 36 | 18 | 22 | 0.0 | 0.0 | 0.0 | 6.8 | - * * |
| 22 | 12 | 23 | 22.0 | 132.0 | 11.0 | 6.1 | * - - |
| 40 | 18 | 23 | 0.0 | 0.0 | 0.0 | 5.8 | * - - |
| 35 | 18 | 20 | 0.0 | 0.0 | 0.0 | 5.7 | - * - |
| 40 | 18 | 22 | 0.0 | 0.0 | 0.0 | 5.7 | - * * |
| 22 | 10 | 23 | 28.0 | 168.0 | 14.0 | 5.6 | * - - |
| 36 | 18 | 23 | 0.0 | 0.0 | 0.0 | 5.6 | - - * |
| 36 | 18 | 20 | 0.0 | 0.0 | 0.0 | 5.4 | - - * |
| 36 | 17 | 22 | 0.0 | 0.0 | 0.0 | 5.2 | - * * |
| 36 | 18 | 21 | 0.0 | 0.0 | 0.0 | 5.2 | - * - |
| 39 | 18 | 19 | 0.0 | 0.0 | 0.0 | 4.9 | - * - |
| 3 | 18 | 23 | 28.0 | 168.0 | 14.0 | 4.9 | - * - |
| 39 | 18 | 20 | 0.0 | 0.0 | 0.0 | 4.9 | - * - |
| 35 | 18 | 19 | 0.0 | 0.0 | 0.0 | 4.8 | - * - |
| 41 | 18 | 21 | 0.0 | 0.0 | 0.0 | 4.8 | - * - |
| 41 | 18 | 20 | 0.0 | 0.0 | 0.0 | 4.7 | - * - |
| 36 | 18 | 24 | 0.0 | 0.0 | 0.0 | 4.7 | - - * |
| 38 | 16 | 19 | 0.0 | 0.0 | 0.0 | 4.7 | - * - |
| 36 | 18 | 19 | 0.0 | 0.0 | 0.0 | 4.6 | - * - |
| 35 | 18 | 21 | 0.0 | 0.0 | 0.0 | 4.6 | - * - |
| 36 | 17 | 20 | 0.0 | 0.0 | 0.0 | 4.5 | - * - |
| 39 | 16 | 19 | 0.0 | 0.0 | 0.0 | 4.5 | - * - |
| 36 | 16 | 22 | 0.0 | 0.0 | 0.0 | 4.3 | - * * |
| 40 | 18 | 20 | 0.0 | 0.0 | 0.0 | 4.2 | - * - |
| 36 | 16 | 19 | 0.0 | 0.0 | 0.0 | 4.2 | - * - |
| 5 | 17 | 24 | 466.0 | 2796.0 | 233.0 | 4.1 | * - - |
| SEARCHING *ITEMP* LIST FOR 17 CAUSED BY 5 17 24 4.143 | | | | | | | |
| 38 | 18 | 17 | 31.0 | 31.0 | 31.0 | 5.2 | |
| 36 | 17 | 19 | 0.0 | 0.0 | 0.0 | 4.1 | - * - |
| 36 | 17 | 23 | 0.0 | 0.0 | 0.0 | 4.0 | - * * |
| 40 | 18 | 19 | 0.0 | 0.0 | 0.0 | 4.0 | - * - |
| 39 | 17 | 19 | 0.0 | 0.0 | 0.0 | 3.9 | - * - |
| 41 | 18 | 19 | 0.0 | 0.0 | 0.0 | 3.8 | - * - |
| 38 | 17 | 19 | 0.0 | 0.0 | 0.0 | 3.7 | - * - |
| 38 | 17 | 20 | 0.0 | 0.0 | 0.0 | 3.6 | - * - |
| 37 | 17 | 22 | 0.0 | 0.0 | 0.0 | 3.6 | - * * |
| 27 | 16 | 19 | 0.0 | 0.0 | 0.0 | 3.6 | - * - |
| 40 | 18 | 21 | 0.0 | 0.0 | 0.0 | 3.6 | - * - |

Until the activity preceding this message was encountered, current-period expected demand for type-17 units had been satisfied for the entire modeled area. The preceding activity, however, used 233 units of housing type 17 as an input to produce 2,796 units of type 24. In this case, reducing the available number of type-17 units also relaxed the demand constraint for that housing type. At this point the submodel re-examines the list of profitable activities, called the *ITEMP* list, to determine whether an earlier, more profitable activity that produces type 17 had been passed over because of the

demand constraint. In this case one such activity was found and reported under the message.

In addition to the list of individual supply activities shown in Exhibit A.3, the supply submodel reports the summaries shown in exhibits A.4 and A.5. As shown in Exhibit A.4, the detail about housing types has been suppressed. The printout is a summary of the

Exhibit A.4 Summary of Supply Activities Classified by Residence Zone

| SUMMARY OF CONVERSIONS FOR YEAR 17 | | | |
|------------------------------------|--------------|-------------|------------|
| ZONE (10) | UNITS OUTPUT | UNITS INPUT | LAIR INPUT |
| 1 | 0.0 | 0.0 | 0.0 |
| 2 | 4579.0000 | 465.0000 | 0.0 |
| 3 | 2092.0000 | 185.0000 | 0.0 |
| 4 | 0.0 | 0.0 | 0.0 |
| 5 | 5256.0000 | 438.0000 | 0.0 |
| 6 | 1992.0000 | 166.0000 | 0.0 |
| 7 | 0.0 | 0.0 | 0.0 |
| 8 | 0.0 | 0.0 | 0.0 |
| 9 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.0 | 0.0 |
| 11 | 1956.0000 | 165.0000 | 0.0 |
| 12 | 225.0000 | 90.0000 | 0.0 |
| 13 | 80.0000 | 80.0000 | 0.0 |
| 14 | 0.0 | 0.0 | 0.0 |
| 15 | 0.0 | 0.0 | 0.0 |
| 16 | 0.0 | 0.0 | 0.0 |
| 17 | 355.0000 | 256.0000 | 0.0 |
| 18 | 0.0 | 0.0 | 0.0 |
| 19 | 12.0000 | 1.0000 | 0.0 |
| 20 | 0.0 | 0.0 | 0.0 |
| 21 | 0.0 | 0.0 | 0.0 |
| 22 | 20352.0000 | 2341.0000 | 0.0 |
| 23 | 0.0 | 0.0 | 0.0 |
| 24 | 0.0 | 0.0 | 0.0 |
| 25 | 0.0 | 0.0 | 0.0 |
| 26 | 1236.0000 | 103.0000 | 0.0 |
| 27 | 685.0000 | 685.0000 | 0.0 |
| 28 | 990.0000 | 990.0000 | 0.0 |
| 29 | 1091.0000 | 1091.0000 | 0.0 |
| 30 | 105.0000 | 82.0000 | 0.0 |
| 31 | 118.0000 | 118.0000 | 0.0 |
| 32 | 108.0000 | 96.0000 | 0.0 |
| 33 | 0.0 | 0.0 | 0.0 |
| 34 | 610.0000 | 610.0000 | 0.0 |
| 35 | 0.0 | 0.0 | 0.0 |
| 36 | 0.0 | 0.0 | 0.0 |
| 37 | 179.0000 | 179.0000 | 0.0 |
| 38 | 0.0 | 0.0 | 0.0 |
| 39 | 653.0000 | 653.0000 | 0.0 |
| 40 | 0.0 | 0.0 | 0.0 |
| 41 | 0.0 | 0.0 | 0.0 |
| 42 | 0.0 | 0.0 | 0.0 |
| 43 | 0.0 | 0.0 | 0.0 |
| 44 | 782.0000 | 782.0000 | 0.0 |

Exhibit A.5 Summary of Supply Activities Classified by Housing Type

| SUMMARY OF CONVERSIONS BY TYPE | | | |
|--------------------------------|-----------------|-------------|--------------|
| HOUSE TYPE | UNFILLED DEMAND | UNITS INPUT | UNITS OUTPUT |
| 1 | -15206.000 | 0.0 | 0.0 |
| 2 | -6856.000 | 0.0 | 0.0 |
| 3 | -6865.000 | 95.000 | 0.0 |
| 4 | -19888.000 | 77.000 | 0.0 |
| 5 | -2494.000 | 0.0 | 0.0 |
| 6 | -2818.000 | 5564.000 | 0.0 |
| 7 | -15774.000 | 0.0 | 0.0 |
| 8 | -5039.000 | 0.0 | 0.0 |
| 9 | -8357.000 | 0.0 | 0.0 |
| 10 | -6941.000 | 14.000 | 0.0 |
| 11 | -1051.000 | 730.000 | 0.0 |
| 12 | -5321.000 | 2846.000 | 0.0 |
| 13 | -6057.000 | 0.0 | 0.0 |
| 14 | 61.000 | 0.0 | 0.0 |
| 15 | 0.0 | 0.0 | 93.000 |
| 16 | -4.000 | 1817.000 | 0.0 |
| 17 | 0.0 | 819.000 | 5194.000 |
| 18 | 0.0 | 569.000 | 328.000 |
| 19 | -4068.000 | 0.0 | 0.0 |
| 20 | -4382.000 | 12.000 | 0.0 |
| 21 | -15724.000 | 0.0 | 0.0 |
| 22 | -11.000 | 102.000 | 11568.000 |
| 23 | -6.000 | 48.000 | 15708.000 |
| 24 | 0.0 | 0.0 | 16776.000 |
| 25 | -22.000 | 0.0 | 1095.000 |
| 26 | -2.000 | 0.0 | 1580.000 |
| 27 | -6517.000 | 0.0 | 0.0 |
| 28 | **** | 0.0 | 0.0 |

total number of dwelling units used as inputs, and the number of acres of land used for new construction in each residence zone. For example, no units are produced by the model in the first zone; as a result, no existing units were used as inputs nor was any vacant land used. In the second zone, however, 4,579 dwelling units were produced during the period by transforming 463 input units.

In contrast, in Exhibit A.5 the zonal detail is suppressed, and the supply activities are summarized by housing type. The summaries indicate how many units of each type were produced as outputs and how many were used as inputs during the time period. The printout also shows the level of unfilled demand for each housing type during this time period, with negative numbers indicating a surplus of the given type and positive numbers indicating a shortage. Housing type 14 is the only one with positive unfilled demand. From Exhibit A.5, then, it is apparent that there was a surplus of all but five types of unit at the end of the period. Since these "surpluses" include an allowance for normal vacancies, the unfilled demand figures listed in Exhibit A.5 will usually be negative.

Several other reports are available which describe each housing submarket in detail, but they are too lengthy to display for any of our actual simulations. A smaller version of the model—10 (residence) by 10 (workplace)—used to debug the program, can be used to illustrate these more detailed tables. Exhibit A.6, which presents sample output from the market-clearing submodel of one of these 10 by 10 examples, illustrates the format used in the Detroit Prototype. The first section of the exhibit contains a list of the demanders of housing type 1 by work zone and income class. Households in which the primary wage earner is employed in zone 1 and belongs to income class 3 are identified by the mnemonic 1-3*.

Exhibit A.6 Sources and Sinks for Market-clearing Submodel: 10 × 10 Version

SOURCE-SINK PROBLEM TO BE SOLVED FOR HOUSE TYPE 1

| SOURCES (FAMILIES SEEKING HOUSES) | | | | | | | | | | | | | | | | | | |
|-----------------------------------|------|------|------|------|------|------|------|-------|-------|------|------|------|------|------|------|------|------|-------|
| 1-1* | 2-1* | 3-1* | 4-1* | 5-1* | 7-1* | 8-1* | 9-1* | 10-1* | 1-2* | 2-2* | 3-2* | 4-2* | 5-2* | 6-2* | 7-2* | 8-2* | 9-2* | 10-2* |
| 1-3* | 2-3* | 3-3* | 4-3* | 5-3* | 6-3* | 7-3* | 8-3* | 9-3* | 10-3* | 1-4* | 2-4* | 3-4* | 4-4* | 5-4* | 6-4* | 7-4* | 8-4* | 9-4* |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 40. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 140. | 0. | 20. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 50. | 0. | 5. | 40. | 0. | 0. | 40. | 5. | 5. |
| SUM = 340. | | | | | | | | | | | | | | | | | | |

| SINKS (HOUSES AVAILABLE BY ZONE) | | | | | | | | | |
|----------------------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1* | 2* | 3* | 4* | 5* | 6* | 7* | 8* | 9* | 10* |
| 52. | 4. | 20. | 62. | 27. | 22. | 26. | 58. | 12. | 78. |

Exhibit A.8
Solution Matrix and Shadow Prices

| OPTIMAL SOLUTION ZONE | | AND | | PRICES | | HOUSE TYPE 1 | | | | | | | | | |
|-----------------------|---|------|------|--------|-----|--------------|-----|-----|-----|-----|-----|-----|--|--|--|
| Z | Y | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | | | | |
| 2 | Y | 111. | 112. | 112. | 67. | 54. | 2. | 15. | 22. | 12. | 0. | | | | |
| 1 | 2 | 111. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 60. | | | |
| 1 | 3 | 121. | 0. | 0. | 6. | 22. | 27. | 8. | 0. | 56. | 15. | 6. | | | |
| 3 | 3 | 77. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 20. | | | |
| 1 | 4 | 122. | 52. | 4. | 14. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | | | |
| 5 | 4 | 84. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 5. | | | |
| 4 | 4 | 67. | 0. | 0. | 0. | 40. | 0. | 0. | 0. | 0. | 0. | 0. | | | |
| 7 | 4 | 13. | 0. | 0. | 0. | 0. | 0. | 14. | 26. | 0. | 0. | 0. | | | |
| 8 | 4 | 22. | 0. | 0. | 0. | 0. | 0. | 0. | 2. | 0. | 0. | 0. | | | |
| 9 | 4 | 12. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 5. | 0. | | | |
| 1 | 5 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 7. | | | |

(rows) may indicate a wage gradient among work zones. Currently we make no use of these wage gradients, but we find them intriguing and plan further investigation of their properties.

Another series of reports describes the price formation section of the market-clearing submodel. Approximately the first half of each of the four possible price matrices is shown in exhibits A.9 through A.12. These price matrices have the dimensions 28 (27 unit types

Exhibit A.9
Current Year's Expected
Prices for Dwelling Units and Land, Housing Types 1-28, Year 1

[illegible]

Exhibit A.11
"Increases" in Expected Prices (Next Year Minus This Year),
Housing Types 1-28, Year 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|------|------|-------|------|------|------|------|-----|------|------|------|------|
| | 26 | 27 | 28 | | | | | | | | | | | | | | | | | | | | | | |
| ZONE | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | -8. | 2. | 5. | 13. | -7. | -13. | -8. | 4. | -6. | 13. | -3. | -47. | -10. | 4. | -13. | 25. | 44. | -93. | -66. | -30. | 40. | 57. | -14. | -6. | |
| 21 | -30. | -11. | -3. | -34. | -19. | -9. | -61. | -42. | -4. | -64. | -30. | -11. | -118. | -56. | -12. | -105. | -50. | 11. | -35. | -34. | -3. | 53. | 68. | -2. | -10. |
| 31 | -18. | -2. | -10. | | | | | | | | | | | | | | | | | | | | | | |
| 41 | -10. | -8. | -4. | 1. | 8. | -11. | -40. | -22. | -5. | -12. | 5. | -17. | -55. | -50. | -9. | -24. | 14. | 33. | -13. | -12. | -4. | 100. | 67. | -0. | -15. |
| 51 | -10. | -1. | -10. | | | | | | | | | | | | | | | | | | | | | | |
| 61 | -2. | -1. | 3. | 18. | 9. | -4. | -4. | -5. | 4. | -4. | 22. | -4. | -46. | -0. | 2. | -11. | 22. | 40. | 5. | -3. | 0. | 90. | 81. | 9. | 1. |
| 71 | -5. | -4. | 3. | 21. | 25. | -9. | -1. | -9. | 1. | 18. | 28. | -10. | -57. | 1. | -4. | 27. | 51. | 34. | -7. | -7. | -2. | 95. | 85. | -3. | -3. |
| 81 | -8. | -2. | -17. | | | | | | | | | | | | | | | | | | | | | | |
| 91 | -3. | 1. | -1. | 13. | 20. | 13. | -6. | -6. | -10. | 18. | 20. | -4. | -34. | -4. | 6. | -22. | 50. | 53. | -1. | -2. | 3. | 93. | 85. | 4. | -4. |
| 101 | -3. | 2. | -13. | | | | | | | | | | | | | | | | | | | | | | |
| 111 | -1. | 3. | -16. | 4. | 17. | 1. | -8. | -10. | 1. | 4. | 12. | -10. | -66. | -4. | 2. | 5. | 40. | 48. | 0. | -2. | -1. | 95. | 83. | 4. | -2. |
| 121 | -1. | 16. | 5. | 13. | 16. | -2. | 2. | -4. | 26. | 25. | 24. | -1. | -7. | 6. | 30. | 7. | 59. | 65. | 4. | 6. | 28. | 106. | 106. | 30. | 9. |
| 131 | 30. | 15. | -6. | | | | | | | | | | | | | | | | | | | | | | |
| 141 | 10. | 10. | -12. | 12. | 18. | -7. | -8. | -6. | 8. | 11. | 22. | -6. | -36. | -4. | 28. | -6. | 45. | 51. | 5. | 3. | 30. | 96. | 93. | 35. | 0. |
| 151 | -3. | -1. | 11. | | | | | | | | | | | | | | | | | | | | | | |
| 161 | -3. | -1. | 7. | 16. | 16. | -10. | -2. | -7. | 2. | 22. | 26. | 7. | -3. | 1. | 7. | 31. | 57. | 46. | 6. | 5. | 8. | 104. | 86. | 12. | 2. |
| 171 | 6. | 12. | -17. | | | | | | | | | | | | | | | | | | | | | | |
| 181 | 33. | 6. | 10. | 15. | 20. | 1. | 0. | 30. | 10. | 36. | 26. | 4. | -25. | 4. | 11. | 10. | 72. | 51. | 35. | 23. | 21. | 141. | 116. | 30. | 20. |
| 191 | 33. | 23. | -3. | | | | | | | | | | | | | | | | | | | | | | |
| 201 | 131. | 7. | 15. | 3. | 13. | -10. | -11. | -10. | 4. | -6. | 10. | 18. | -60. | -7. | 18. | -20. | 26. | 45. | -15. | -8. | 8. | 78. | 66. | 23. | 8. |
| 211 | -12. | -4. | 2. | -6. | 11. | -12. | -5. | -15. | 7. | 3. | -0. | -12. | -65. | 1. | 12. | 7. | 32. | 43. | -8. | -7. | 0. | 79. | 63. | 17. | 7. |
| 221 | 8. | 23. | 6. | | | | | | | | | | | | | | | | | | | | | | |
| 231 | 15. | 0. | 6. | 7. | 8. | -4. | -8. | 13. | 1. | -10. | 17. | -8. | -41. | 2. | 16. | -13. | 24. | 37. | 3. | -3. | 3. | 111. | 97. | 26. | 24. |
| 241 | 27. | 26. | 11. | | | | | | | | | | | | | | | | | | | | | | |
| 251 | -14. | -2. | 11. | -7. | 12. | -3. | -10. | -17. | 7. | -3. | 4. | -5. | -36. | -7. | 19. | -1. | 29. | 63. | -8. | -9. | 0. | 75. | 78. | 21. | 8. |
| 261 | 10. | 27. | 7. | | | | | | | | | | | | | | | | | | | | | | |
| 271 | 7. | 4. | 16. | 10. | -8. | 4. | -15. | -10. | 1. | -53. | 7. | -14. | -12. | 1. | 9. | -0. | 3. | 16. | -23. | -12. | 25. | 45. | 86. | 33. | 23. |
| 281 | 17. | 27. | 14. | | | | | | | | | | | | | | | | | | | | | | |
| 291 | -24. | 3. | 13. | 2. | -6. | -5. | -36. | -39. | 2. | -21. | 5. | -10. | -4. | -23. | 9. | 8. | 9. | 20. | -17. | -20. | -7. | 86. | 70. | 13. | 10. |
| 301 | 7. | 15. | 9. | | | | | | | | | | | | | | | | | | | | | | |
| 311 | -48. | -7. | 6. | -11. | -18. | -3. | -47. | -90. | -4. | -33. | -2. | -26. | -22. | -39. | 10. | -7. | -0. | 14. | -27. | -23. | -4. | 84. | 70. | 21. | 31. |
| 321 | 20. | -46. | -1. | -12. | -21. | -6. | -51. | -51. | -3. | -34. | -4. | -30. | -23. | -40. | 12. | -15. | -10. | 10. | -46. | -34. | 7. | 65. | 55. | 26. | 27. |
| 331 | 28. | 31. | 18. | | | | | | | | | | | | | | | | | | | | | | |
| 341 | -6. | 5. | 13. | 14. | 15. | 13. | -8. | -3. | 11. | 16. | 20. | 2. | -25. | 2. | 25. | 9. | 49. | 50. | -15. | -4. | 9. | 85. | 82. | 25. | 3. |
| 351 | 12. | 28. | 8. | | | | | | | | | | | | | | | | | | | | | | |
| 361 | -35. | -4. | 10. | 14. | -13. | -4. | -33. | -39. | 5. | 1. | 23. | -19. | -15. | -31. | 14. | 3. | 35. | 22. | -21. | 34. | 6. | -13. | -12. | -17. | -34. |
| 371 | -53. | -22. | 8. | | | | | | | | | | | | | | | | | | | | | | |
| 381 | -41. | -9. | -12. | -9. | -3. | -7. | -25. | -47. | -3. | -27. | -1. | -26. | -20. | -16. | 9. | -10. | 4. | 28. | 6. | 3. | 16. | 127. | 103. | 34. | 25. |
| 391 | 26. | 26. | 7. | | | | | | | | | | | | | | | | | | | | | | |

Exhibit A.12
Location Rents for Housing Types 1-28 and Land, Year 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 26 | 27 | 28 | | | | | | | | | | | | | | | | | | | | | | |
| ZONE | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 16. | 21. | 13. | 27. | 29. | 17. | 16. | 14. | 16. | 24. | 31. | 18. | 18. | 19. | 27. | 33. | 37. | 40. | 16. | 14. | 11. | 49. | 50. | 20. | 20. |
| 21 | 16. | 14. | 50. | | | | | | | | | | | | | | | | | | | | | | |
| 31 | 12. | 12. | 0. | 24. | 20. | 2. | 7. | 10. | 0. | 24. | 20. | 7. | 18. | 16. | 10. | 30. | 26. | 36. | 12. | 2. | 0. | 44. | 34. | 2. | 13. |
| 41 | 2. | 0. | 44. | | | | | | | | | | | | | | | | | | | | | | |
| 51 | 13. | 15. | 0. | 28. | 23. | 2. | 9. | 9. | 0. | 27. | 22. | 4. | 21. | 15. | 12. | 33. | 29. | 33. | 14. | 4. | 0. | 47. | 36. | 2. | 10. |
| 61 | 7. | 8. | 1. | 20. | 16. | 5. | 2. | 0. | 2. | 19. | 14. | 0. | 12. | 7. | 14. | 24. | 23. | 35. | 13. | 0. | 0. | 39. | 32. | 17. | 18. |
| 71 | 15. | 13. | 39. | | | | | | | | | | | | | | | | | | | | | | |
| 81 | 0. | 1. | 0. | 14. | 16. | 0. | 0. | 0. | 0. | 5. | 17. | 5. | 0. | 2. | 0. | 13. | 26. | 34. | 0. | 0. | 0. | 36. | 36. | 0. | 7. |
| 91 | 0. | 0. | 36. | | | | | | | | | | | | | | | | | | | | | | |
| 101 | 0. | 7. | 32. | | | | | | | | | | | | | | | | | | | | | | |
| 111 | 0. | 1. | 14. | 15. | 5. | 6. | 0. | 0. | 0. | 6. | 18. | 4. | 3. | 7. | 16. | 17. | 32. | 33. | 2. | 0. | 0. | 36. | 36. | 7. | 0. |
| 121 | 6. | 7. | 36. | | | | | | | | | | | | | | | | | | | | | | |
| 131 | 8. | 26. | 40. | 6. | 4. | 10. | 0. | 0. | 9. | 6. | 17. | 8. | 0. | 7. | 40. | 5. | 28. | 21. | 0. | 3. | 31. | 23. | 10. | 27. | 3. |
| 141 | 0. | 6. | 8. | 18. | 21. | 5. | 0. | 7. | 4. | 9. | 22. | 10. | 0. | 13. | 25. | 18. | 29. | 39. | 0. | 0. | 5. | 41. | 41. | 11. | 14. |
| 151 | 11. | 14. | 41. | | | | | | | | | | | | | | | | | | | | | | |
| 161 | 0. | 0. | 0. | 3. | 4. | 7. | 0. | 1. | 16. | 3. | 15. | 0. | 0. | 7. | 54. | 13. | 25. | 27. | 13. | 8. | 17. | 18. | 18. | 40. | 17. |
| 171 | 14. | 29. | 34. | | | | | | | | | | | | | | | | | | | | | | |
| 181 | 8. | 8. | 7. | 16. | 16. | 18. | 9. | 8. | 17. | 15. | 23. | 11. | 9. | 14. | 30. | 19. | 39. | 32. | 7. | 10. | 8. | 34. | 33. | 17. | 10. |
| 191 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 201 | 8. | 10. | 11. | 17. | 17. | 15. | 10. | 10. | 10. | 15. | 28. | 14. | 13. | 17. | 22. | 12. | 42. | 35. | 10. | 10. | 10. | 36. | 36. | 16. | 13. |
| 211 | 15. | 14. | 42. | | | | | | | | | | | | | | | | | | | | | | |
| 221 | 0. | 0. | 6. | 11. | 12. | 11. | 0. | 0. | 18. | 1. | 12. | 3. | 0. | 5. | 52. | 22. | 20. | 33. | 21. | 0. | 11. | 32. | 32. | 34. | 27. |
| 231 | 23. | 28. | 52. | | | | | | | | | | | | | | | | | | | | | | |
| 241 | 0. | 0. | 0. | 2. | 0. | 0. | 0. | 0. | 5. | 0. | 1. | 0. | 0. | 11. | 41. | 11. | 10. | 25. | 22. | 0. | 0. | 35. | 34. | 31. | 55. |
| 251 | 29. | 32. | 41. | | | | | | | | | | | | | | | | | | | | | | |
| 261 | 0. | 10. | 11. | 0. | 10. | 9. | 0. | 9. | 2. | 0. | 10. | 0. | 17. | 21. | 51. | 12. | 20. | 22. | 31. | 10. | 9. | 45. | 44. | 44. | 43. |
| 271 | 40. | 44. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 281 | 0. | 1. | 0. | | | | | | | | | | | | | | | | | | | | | | |
| 291 | 27. | 39. | 32. | 0. | 0. | 0. | 0. | 0. | 12. | 0. | 12. | 1. | 11. | 6. | 52. | 17. | 19. | 24. | 23. | 0. | 2. | 25. | 23. | 39. | 34. |
| 301 | 35. | 35. | 33. | 32. | 28. | 8. | 0. | 0. | 28. | 8. | 0. | 35. | 36. | 43. | 30. | 15. | 30. | 45. | 0. | 13. | 27. | 40. | 35. | 90. | |
| 311 | 31. | 35. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 321 | 19. | 19. | 19. | 10. | 15. | 0. | 0. | 0. | 15. | 0. | 6. | 0. | 10. | 24. | 32. | 16. | 13. | 20. | 30. | 0. | 1. | 27. | 28. | 26. | 36. |
| 331 | 22. | 25. | 36. | | | | | | | | | | | | | | | | | | | | | | |
| 341 | 4. | 9. | 10. | 0. | 9. | 8. | 3. | 8. | 16. | 6. | 16. | 0. | 14. | 21. | 51. | 21. | 26. | 30. | 30. | 9. | 8. | 45. | 45. | 42. | 42. |
| 351 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 201 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 211 | 8. | 10. | 11. | 16. | 11. | 11. | 7. | 10. | 0. | 18. | 20. | 0. | 23. | 22. | 61. | 20. | 16. | 29. | 32. | 15. | 10. | 46. | 45. | 50. | 44. |
| 221 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 231 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 241 | 8. | 10. | 11. | 16. | 11. | 11. | 7. | 10. | 0. | 18. | 20. | 0. | 23. | 22. | 61. | 20. | 16. | 29. | 32. | 15. | 10. | 46. | 45. | 50. | 44. |
| 251 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 261 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 271 | 8. | 10. | 11. | 16. | 11. | 11. | 7. | 10. | 0. | 18. | 20. | 0. | 23. | 22. | 61. | 20. | 16. | 29. | 32. | 15. | 10. | 46. | 45. | 50. | 44. |
| 281 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 291 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 301 | 8. | 10. | 11. | 16. | 11. | 11. | 7. | 10. | 0. | 18. | 20. | 0. | 23. | 22. | 61. | 20. | 16. | 29. | 32. | 15. | 10. | 46. | 45. | 50. | 44. |
| 311 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 321 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |
| 331 | 8. | 10. | 11. | 16. | 11. | 11. | 7. | 10. | 0. | 18. | 20. | 0. | 23. | 22. | 61. | 20. | 16. | 29. | 32. | 15. | 10. | 46. | 45. | 50. | 44. |
| 341 | 39. | 42. | 51. | | | | | | | | | | | | | | | | | | | | | | |
| 351 | 11. | 10. | 30. | | | | | | | | | | | | | | | | | | | | | | |

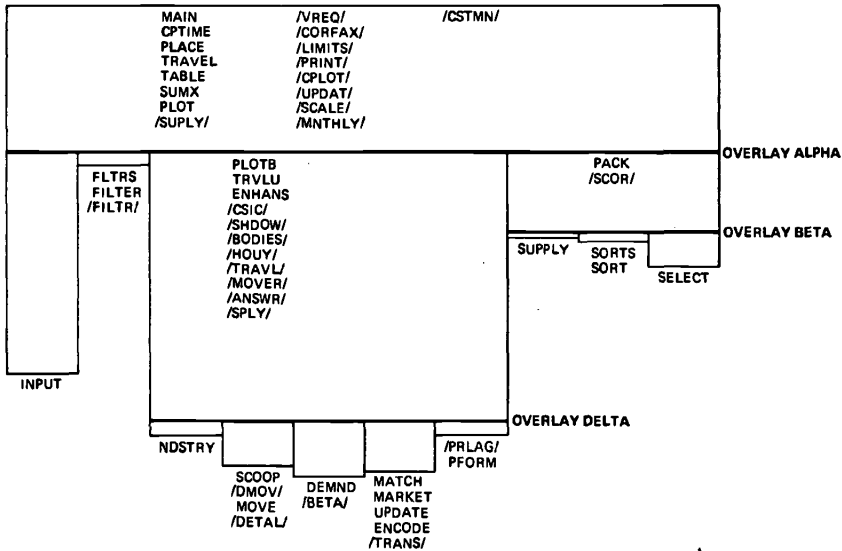
Program Description

The computer program is mostly written in FORTRAN IV, for the IBM 360 series. The few assembly language routines used are self-contained subroutines which perform specialized functions such as manipulating characters for creating plots and reading elapsed CPU time. The program is a composite of many subroutines. This allows convenient local modifications to be made with generally good assurance of a successful subsequent run. On the other hand, the program makes extensive use of the overlay option in order to economize on restricted core space. The use of this option demands considerable sophistication about data storage on disks and its subsequent retrieval. Experienced programmers who are knowledgeable about these methods should find it relatively easy to modify the program. However, inexperienced programmers will discover that modifications appear to be simple, but that somehow subsequent simulation runs are never successful.

Table A.3
Submodels and Subroutines

| Submodel | Subroutines | Block Common |
|---------------------|---|---|
| Employment location | <i>NDSTRY</i> | /LIMITS/,/CORFAX/, /BODIES/,/CSIC/, /TRAVL/,/UPDAT/ |
| Movers | <i>MOVE, SCOOP, ENHANS</i> | /CORFAX/,/UPDAT/, /BODIES/,/TRAVL/, /MOVER/,/DMOV/, /DETAL/,/HOUY/ |
| Demand allocation | <i>DEMND</i> | /CORFAX/,/BODIES/, /TRAVL/,/MOVER/, /BETA/ |
| Filter | <i>FLTRS, FILTER</i> | /FILTR/,/LIMITS/, /CORFAX/,/SCALE/ |
| Supply | <i>SUPPLY, SORT, SORTS, SELECT, PACK</i> | /CORFAX/,/SUPPLY/, /CSTMN/,/SCOP/, /VREQ/ |
| Market-clearing | <i>MARKET, ENCODE, MATCH, UPDATE, PFORM</i> | /TRAVL/,/SPLY/, /MOVER/,/ANSWR/, /TRANS/,/SHDOW/, /PRLAG/,/MNTLY/ |

Figure A.2
Overlay Map of Program



The operational model consists of a main program and eleven overlay segments. These eleven segments in turn comprise 26 subroutines and 25 named block common storage areas. Table A.3 shows the relation of the seven submodels to the subroutines and block common areas. Figure A.2 is a schematic of the model's overlay structure. The relative positions of overlays alpha, beta, and delta depend on the size of the problem being attacked. In the Detroit Prototype program, alpha is located about 71,000 bytes from the origin; beta, about 120,000 bytes; and delta, about 191,000 bytes.

Maximum core requirements vary according to the compiler used, but the maximum core size is determined by the end of *DEMND* in the Detroit Prototype, and it is about 229,000 bytes from the origin. Generally, additional amounts of core are required for various system-monitoring and program-linking routines; so the Detroit Prototype program requires approximately 250K bytes of nonsystem core.